

DOMESTIC WASTE WATER DISPOSAL
AND
NUTRIENT REMOVAL
BY
SEPTIC TANK-SAND FILTER SYSTEM

REPORT #77

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1979



Ministry
of the
Environment

The Honourable
Harry C. Parrott, D.D.S.,
Minister

Graham W. S. Scott,
Deputy Minister

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by:

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1979

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ABSTRACT

A Septic tank - Sand Filter System containing a naturally occurring mineral, clinoptilolite, and a waste by-product of bauxite purification, "red mud", mixed with sand, will treat water borne domestic waste with an efficiency for the removal of nitrogen and phosphorus nutrients of about 90% besides achieving high levels of BOD₅ and suspended solids removal.

The useful life and efficiency of the system for removing the nutrients from the waste will depend on the quantity of the additives in the sand filter.

PROJECT STAFF

The following staff of the Ministry were instrumental in the production of this report:

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1.0 GENERAL

Eutrophication in the aquatic system is a natural evolutionary process. Man's activities however, have often been implicated in accelerating this process. The elements considered to be playing a major role in the eutrophication are carbon, nitrogen and phosphorus acting individually or through combination of the three resulting in an increased or excessive production of algae. The possible sources through which these elements can enter streams and lakes are; untreated or partially treated effluents from municipal sewage plants and private waste disposal systems, garbage disposal, industrial wastes, atmosphere, land run off, rainfall etc.

In areas remote from municipal facilities, a large number of private, on-site, sub-surface waste disposal systems are presently in use and their number is increasing every year. It therefore has become necessary to evaluate and establish methods which are capable of eliminating nitrogen from the waste without requiring operational supervision.

2.0 PHOSPHORUS AND NITROGEN

2.1 Phosphorus

The presence of phosphorus in the various discharges into the lakes has been stated to be the limiting factor for aquatic growth. It had been estimated that synthetic detergents contributed more than 50% of the phosphates in wastewater discharged into the lakes and streams of North America.^(1,2) The permissible level of phosphorus in this country was reduced from 38% to 20% as P_2O_5 in detergent formulas (excluding dishwashing detergents) as of August 1, 1970. This was further restricted⁽³⁾ to a maximum of 5% as P_2O_5 effective January 1, 1973.

The increased emphasis on the removal of phosphorus from waste water has brought forth a number of specific treatment schemes. Basically, the various removal approaches include chemical processes, biological treatment, combination of chemical-biological processes and a variety of miscellaneous processes eg. ion exchange, electro-dialysis, effluent spraying on land, reverse osmosis, electrochemical treatment and distillation, etc. Consequently, in many sewage treatment plants, phosphorus is being removed by a method selected on the basis of economic feasibility.

2.2 Nitrogen

The control of nitrogen in the aquatic environment may be required for several reasons in addition to its role as an algae nutrient. The discharge of effluents containing ammonia exerts environmental stress in receiving waters.⁽⁴⁾ It has been demonstrated^(5,6,7) that oxygen demand exerted during oxidation of NH_4^+ is at least as severe as that for

carbon. By decreasing the dissolved oxygen concentration, nitrification process would inhibit aquatic metabolism ⁽⁸⁾. Some types of fish may be adversely affected by the presence of 0.5 mg/L of ammonia. In concentrations of as little as 0.3 mg/L, ammonia has been found to be toxic to trout fry and rainbow trout ⁽⁹⁾.

The concentration of nitrates in ground water in some areas such as those having multi-unit housing developments using individual sub-surface waste treatment system and well water supply could be higher than those accepted by Regulatory Agencies.

Water with high levels of nitrates when consumed by infants may affect the hemoglobin in the blood, preventing it from carrying oxygen creating a condition known as methemoglobinemia or "blue baby" syndrome.

A number of processes, biological and physical chemical, investigated for the removal of nitrogen from wastewater have been described in literature.

The biological nitrification-denitrification process essentially consists of oxidizing nitrogen compounds to nitrates by microorganisms of the autotrophic bacterial groups eg. Nitrosomonas and Nitrobacter in aerobic environments. When the nitrified effluents are subjected to anaerobiosis in the presence of commonly found facultative heterotrophic bacteria such as Pseudomonas, Micrococcus, Achromobacter and Spirillum, which can use nitrates rather than oxygen as electron acceptors, the nitrates and nitrites are reduced into nitrogen gas. ⁽¹⁰⁾ Reduction of nitrate however, may proceed very

slowly in the absence of biodegradable organic matter. Among a number of organic compounds such as sugar, methanol and ethanol used for accelerating biological denitrification, methanol, considering the costs, appears to be the most suitable for the purpose. The disadvantages however, are that 100% nitrogen removal may not be attainable and toxic compounds may affect stability.^(11,12,13)

In domestic wastewater more than 90% of nitrogen is present in the form of ammonia or compounds from which ammonia is readily formed. Under aerobic conditions this is converted ultimately into nitrates. If however, this oxidation process could be controlled, the removal of ammonia by stripping has been considered to be economical⁽¹⁴⁾ along with some operational advantages as compared to nitrate removal. The process essentially consists of raising the pH of the water in the range of 10 to 11.5 and blowing air through a stripping tower to provide air-water contact. The limitation of this process is that it can remove only ammonia nitrogen. The other disadvantages are poor operation in winter temperatures and reduced air circulation due to deposition of calcium carbonate on the packing material with possibility of clogging of the tower.

Ion exchange for the removal of ammonia from wastewater by zeolite filter was used in the Gugenheim Process.^(15,16) Nesselson investigated the use of Amerlite 1R-120 and Nalcite HCR resins for ammonia removal from activated sludge effluent.⁽¹⁷⁾ At the South Tahoe Utilities, Duolite C-25 resin for the same purpose was investigated.^(18,19) Ames and Mercer et al^(20,21) examined the use of Clinoptilolite for a similar study with great success.

Smith et al (22) have reported high degree of removal of nitrogen by Reverse Osmosis whereas Eliasson (23) has experimented using electro-dialysis process and obtaining high quality water. Both of these processes however, are uneconomical. In addition there are the problems of regeneration liquid waste disposal and fouling of the membranes.

Break-point chlorination could achieve a high degree of removal of ammonia and is not influenced by temperature (24,25). The cost of this process depends on ammonia concentration in the wastewater. The process could form chlorinated organics as well as some nitrates.

The final selection of a method for removing nitrogen from wastewater would depend mainly on a) the degree of treatment required, (b) the type of ultimate disposal, (c) the economic feasibility and (d) the environmental compatibility. Any of the processes selected may be adopted for municipal sewage treatment plants where the facilities are under the control and constant supervision of trained personnel. For private waste disposal however, the process should also be capable of operating with little attention and maintenance.

3.0 PRIVATE WASTE DISPOSAL

3.1 Septic Tank and Tile Field

In areas remote from municipal facilities, properly designed, constructed and operated private waste treatment systems consisting of septic tanks and tile fields are considered to be satisfactory and widely accepted for subsurface disposal of domestic water borne waste. The systems are designed to remove settleable solids, reduce biochemical oxygen demand and eliminate microorganism contaminants before the waste effluent reaches an aquifer or other body of water. In a properly installed system, most of the organic contaminants in the septic tank effluent decompose while percolating through soil. The phosphorus is generally retained by soil through chemical reaction or adsorption on silty-clay particles. The nitrogenous compounds, however, are decomposed biologically into elemental nitrogen and/or oxidized into stable form mainly as nitrates before reaching the ground water. Some of the phosphorus and nitrogen is taken up by the surrounding vegetation for its growth.

3.2 Septic Tank and Sand Filter

In situations where conventional subsurface disposal methods are impractical due to high water table, bed rock, insufficient soil or unsatisfactory soil characteristics, a septic tank with a sand filter is considered to be a possible alternative for the treatment of sewage. In a previous study ⁽²⁶⁾ widely available sands, classified at the gravel pits as "block sand", "concrete sand", "medium sand" and "pea gravel" etc. were used to observe their capacity for treatment of the waste. These filters were able to treat septic tank effluent with an efficiency for

BOD and suspended solids removal of more than 90%. The efficiency for phosphorus removal however, was generally less than 34%.

3.2.1 Phosphorus

In order to further reduce phosphorus content in the effluent, sand was mixed with red mud (residue from the bauxite purification process containing oxides of calcium, aluminum and iron), crushed limestone or silt and clay. This enabled removal of phosphorus with an efficiency of more than 90%. The capacity for removal however, depends on the nature, chemical characteristics and the quality of the additive mixed with the filter sand. (27,28,29)

3.2.2 Nitrogen

In the effluents from sand filters, the nitrate concentration was found to be 30-40 mg/L N. The free ammonia on the average was less than 0.1 mg/L.

The samples collected from bore holes in a conventional subsurface waste disposal tile field contained 15-20 mg/L N as nitrate. There could however, be some further dilution by its mixing with ground water.

3.4 Clinoptilolite and Nitrogen

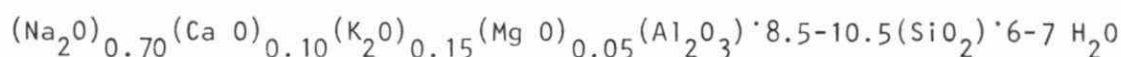
On examination of various methods for the removal of nitrogen from municipal sewage, and in view of the limitations of each, it appeared that an ion exchange process could be adopted for private waste treatment. For such process synthetic resins or natural zeolites could be used.

One of the zeolites investigated for ion exchange was naturally occurring clinoptilolite. (14,15,24)

The general formula in the silicate group for the composition of zeolites is:

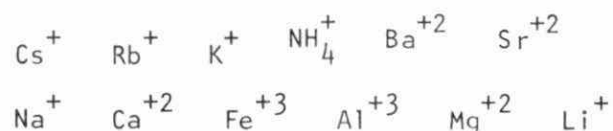


where M and N are alkali metal and alkaline earth respectively. Clinoptilolite has been defined as a mineral of the zeolite group having a molecular composition close to:



This mineral, like other zeolites, can be reversibly dehydrated without undergoing a change in crystal structure and is capable of undergoing cation exchange.

Clinoptilolite is found in abundance in large surface deposits in the Western United States, as well as near Hector in Southern California. It has a high selectivity for ammonium ions compared with its selectivity for sodium, calcium and magnesium ions. Ames (20,31) determined the equilibrium isotherms for ammonia and other cations. These isotherms indicated that clinoptilolite is selective for ammonia relative to all other ions, except potassium, usually present in waste waters. The selectivity for various cations reported was:



Koon et al (30) studied the factors influencing the exhaustion performance and optimization of the regeneration cycle of clinoptilolite in municipal wastewater

treatment. Sims and Little ⁽³²⁾ investigated use of this zeolite for enhancing nitrification process in activated sludge plants.

Ion exchange capacity is an indication of the applicability of the substance for any process use. The total ion exchange capacity of Clinoptilolite given by various investigators ranges from 1.6 to 2.0 m eq/g. This mineral, like synthetic resins when used in ion exchange process would require periodic regeneration on-site for repeated use. If however, the quantity of the exchange mineral for the system had capacity adequate for treatment on a long term basis it could be economically feasible to replace the material after it was exhausted and the used material regenerated away from the site.

On the basis of the above a pilot study was initiated to study the use of clinoptilolite for nitrogen removal as part of a private waste treatment system.

4.0 EQUIPMENT AND OPERATION

The clinoptilolite was kept immersed overnight in a 2% solution of sodium chloride and then washed with distilled water. This material with effective size (D_{10}) = 0.5 mm and uniformity coefficient (Cu) = 1.8 was used for this study.

Three plexiglass columns, 10 cm inside diameter and 1.8 metre in length were used. The details for packing of the columns are given in Figure 1. Column I contained clinoptilolite; column II had red mud and sand. These two columns were connected in series. Column III, packed similarly to column II, was used as a control.

Columns I and III were loaded simultaneously with sewage through an electric valve and timer arrangement fourteen times a day at the daily rate of 50 L/m². During Phase I the raw sewage entered column I at the bottom, coming out from the top, then entering column II at the top and discharging from the bottom. The arrangement kept column I under anaerobic conditions for the incoming sewage to come in contact with clinoptilolite for removing ammonium nitrogen. Column III received the sewage at the top and discharged from near the bottom of the column.

The samples of the influent and the effluent from the three columns were collected weekly and analyzed. The columns continued to operate satisfactorily for over seven months after which column I, containing clinoptilolite, showed a tendency to clog at the inlet and ultimately flow of effluent from this column into column II was greatly reduced. At that stage operation of this system was discontinued.

Column I was emptied and repacked with clinoptilolite mixed 50% with sand of effective size

(D_{10}) = 0.30 mm and Uniformity Coefficient (Cu) = 4.0.
Columns II and III were left undisturbed.

For Phase II of the study, effluent from a 2,700 litre septic tank instead of raw sewage was used as the influent to the columns. The feed to column I entered near the top of the column instead of at the bottom in order to be able to rake the clogging layer from the surface at the interface of sewage and the mineral if found necessary during operation of the system. The effluent from the bottom of column I entered at the top of column II thereby keeping column I always under anaerobic conditions as in Phase I.

No change was made in the direction of flow of the waste for columns II and III each containing red mud and sand. The arrangement of the columns is shown in Figure 2.

The system has been in operation for more than $1\frac{1}{2}$ years without any apparent signs of clogging of the materials.

5.0 RESULT AND DISCUSSION

The statistical analyses for 15%, 50% and 85% of the samples of the influents and the effluents for various parameters are given in Table 1 and Table 2 for Phase I and Phase II respectively.

5.1 Phase 1 Raw Sewage Influent

5.1.1 BOD₅ and Suspended Solids

The BOD and suspended solids values in the effluent from the columns, as expected from sand filter results, were less than 5 mg/L in 85% of the samples. The raw sewage used as influent to the columns had BOD and suspended solids of 170 mg/L and 330 mg/L respectively.

5.1.2 Free Ammonia-N

The concentration of free ammonia-N in the influent to the columns was equal to or less than 18.0 mg/L and 23.5 mg/L in 50% and 85% of the samples respectively. The concentration of ammonia in the effluents from the three columns was always less than 0.1 mg/L.

5.1.3 Nitrite-N

The nitrite-N content in the influent and the effluents all the time was less than 0.1 mg/L.

5.1.4 Total Kjeldahl-N

The effluent from column I containing Clinoptilolite had Kjeldahl nitrogen concentration in 50% and 85% of the samples equal to or less than 1.9 mg/L and 2.7 mg/L respectively. The corresponding raw

sewage values were 28.3 mg/L and 35.2 mg/L. This showed a reduction in nitrogen of more than 92%. The effluent from column I after passing through column II, showed some further reduction from 2.7 mg/L to 2.1 mg/L.

5.1.5 Nitrate-N

The clinoptilolite retained most of the nitrogen and the nitrate-nitrogen concentration in the effluent from column I and II was less than 1.5 mg/L N in 85% of the samples. The corresponding concentration in the effluent from the control column III was equal to or less than 38 mg/L N.

5.1.6 Nitrogen Balance

Nitrogen (mg/L) (N)	Input	Output II Clin + Sand + Red Mud	Output III Sand + Red Mud
Free Ammonia-N	23.5	≤ 0.1	0.1
Organic-N	16.7	2.0	0.7
Nitrite-N	≤ 0.1	≤ 0.1	≤ 0.1
Nitrate-N	0.2	1.5	38.0
TOTAL ± 0.1	40.4	3.6	38.8

The treatment by clinoptilolite of raw sewage containing up to 40.4 mg/L of nitrogen reduced it to 3.5 mg/L or less in the final effluent; the efficiency of removal was 90%.

5.1.7 Phosphorus-P

The concentration of phosphorus P in the effluent from column II containing "red mud" and treating effluent discharged from clinoptilolite column I (1.5 mg/L or less) was similar to that from the control column III which also contained "red mud" but received raw sewage.

5.2 Phase II Septic Tank Effluent Feed

Table 2 gives a summary of the results of the analyses using septic tank effluent as input feed to the columns. During operation of the system, for over 1½ years, using sand mixed with clinoptilolite there has been no problem of clogging of the material. The efficiency of treatment of the waste through the columns as indicated by BOD and Suspended Solids has been similar to that during Phase I. The free ammonia-N in the effluent from column II was equal to or less than 0.1 mg/L. The nitrate-N content in the effluent from the two columns with and without clinoptilolite was 2.6 mg/L and 36 mg/L respectively.

The residual phosphorus in clinoptilolite-red mud system has been similar to the control system with red mud but without the zeolite. The concentration of phosphorus in 85% of the samples was less than 0.6 mg/lL.

5.2.1 Nitrogen Balance

Nitrogen mg/L (N)	Input	Output II Clin + Sand + Red Mud	Output III Sand + Red Mud
Free Ammonia-N	28.0	≤ 0.1	≤ 0.1
Organic-N	11.0	1.6	0.2
Nitrite-N	≤ 0.1	≤ 0.1	≤ 0.1
Nitrate-N	0.1	2.6	36.0
TOTAL ± 0.1	39.2	4.3	36.3

The total nitrogen removal efficiency by the clinoptilolite-sand system was 89% or more.

6.0 COST FOR NITROGEN REMOVAL

Estimated costs for using clinoptilolite in a sand filter for private waste treatment from a residence occupied by a family of four would be:

Water used by a family of four	=	180 x 4
	=	720 L/day
Average nitrogen in septic tank effluent	=	30 mg/L
Total Nitrogen per day	=	720 x 30
	=	21.6 g/day
Total Nitrogen in 365 days	=	21.6 x 365
	=	7,884 g/yr.
Capacity of Clinoptilolite	=	1.86 ^{mg/g} mg/g
Considering NH ₄ -N Capacity	=	1.86 x 0.014
	=	0.026 g/g
Clinoptilolite required	=	<u>7.884</u>
		0.026
	=	303.2 x 10 ³ g
	=	303.2 Kg
Cost per Kg of Clinoptilolite (F.O.B. Houston Texas)	=	\$0.55/Kg
Cost for 303.2 Kg Clinoptilolite	=	303.2 x 0.55
	=	\$166.78/yr
	approx. =	\$170.00
Cost of Clinoptilolite for 10 yrs. installation (without regeneration)	=	\$1,700.00

7.0 SUMMARY

- 1) The efficiency for treatment of waste for the removal of BOD and suspended solids through a sand-clinoptilolite - red mud filter continues to be more than 96% after more than one year.
- 2) There was no significant effect on the efficiency of phosphorus removal with red mud after treating the waste by sand-clinoptilolite system.
- 3) A sand filter containing the mineral clinoptilolite would reduce nitrogen content from raw sewage or septic tank effluent with an efficiency of more than 90%.
- 4) In a septic tank-sand filter system additional cost for including clinoptilolite for a residence occupied by a family of four persons is estimated to be approximately \$2,000.00 for ten years after which the mineral could be replaced. The cost may be reduced if arrangements are available for regenerating the zeolite, off site, every few years when a corresponding lesser quantity of the material in the installation would be required.

8.0 CONCLUSIONS

- 1) For location where a conventional septic tank-tile field system cannot be installed, a properly designed septic tank-sand filter is a possible alternative.
- 2) In cases where the soil around a sand filter is not adequate (does not contain silt and clay) for retaining phosphorus, red mud can be used as an additive in the sand filter.
- 3) In locations such as multiple dwellings serviced by individual septic tank and subsurface disposal systems, and wells for water supply or where the nitrate content in the aquifer is higher than the Regulating Standards, Clinoptilolite mineral could be incorporated in the sand filter system for liquid waste treatment to remove nitrogen compounds.
- 4) A filter consisting of sand, clinoptilolite and red mud may be an economical alternative in situations where phosphorus and nitrogen, in addition to carbon must be removed from private waste.

PHASE I

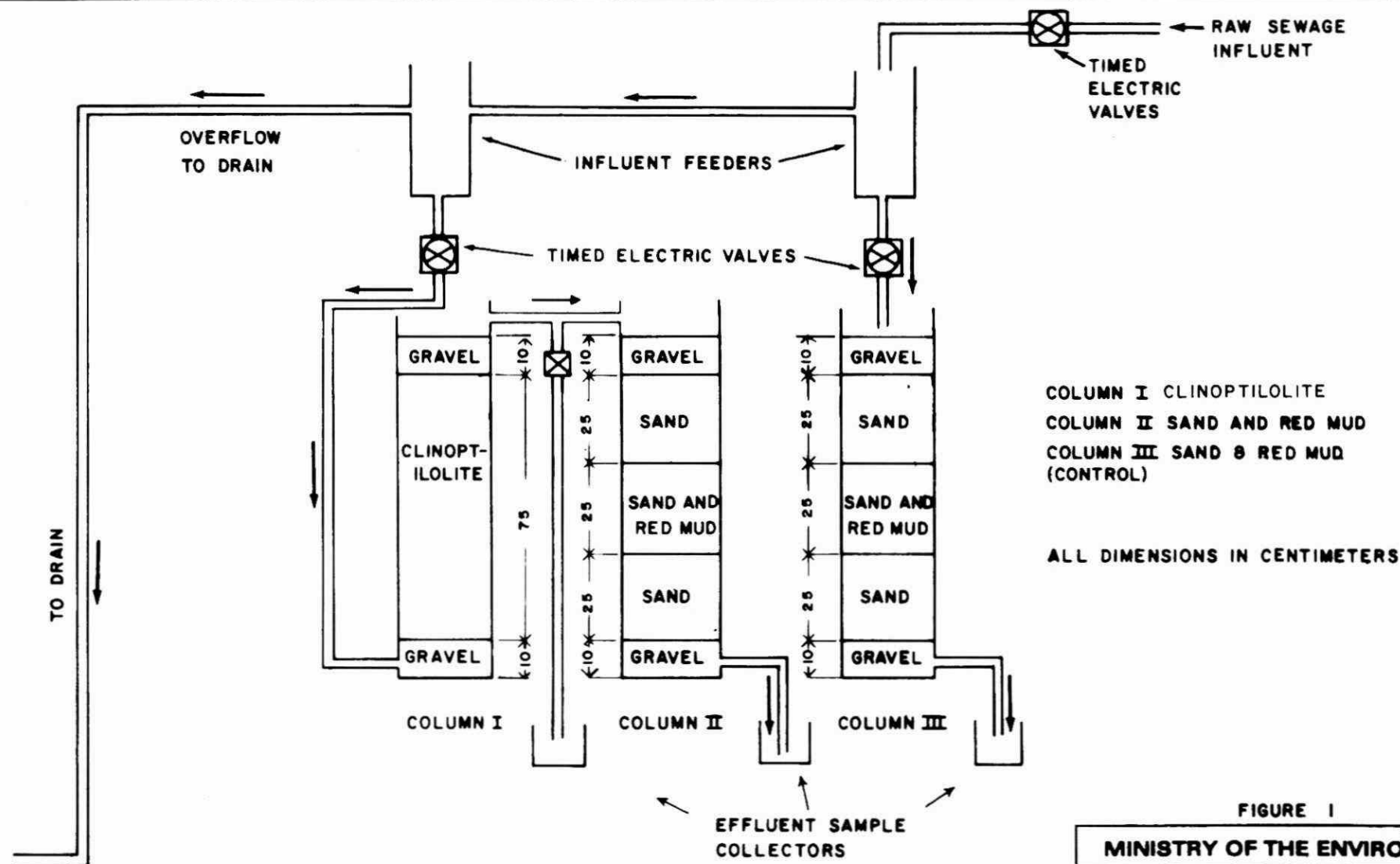
Analysis of Effluents

	Raw Sewage			Effluent Column I Clinoptilolite			Effluent Column II Red Mud & Sand			Effluent Column III Red Mud & Sand		
	% O F T I M E V A L U E S E Q U A L T O O R L E S S T H A N											
	15	50	85	15	50	85	15	50	85	15	50	85
BOD ₅	65	105	170	-	-	-	0.9	2.0	4.5	0.5	1.0	2.2
Suspended Solids	65	130	330	-	-	-	<5	<5	<5	<5	<5	5
Ammonia - N	14.0	18.0	23.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Kjeldahl - N	20.4	28.3	40.2	1.4	1.9	2.7	0.7	1.3	2.1	0.4	0.6	0.8
Nitrite - N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrate - N	<0.1	<0.1	<0.2	<0.1	<0.5	<1.0	<0.1	<0.1	1.5	22.0	28.0	38.0
Phosphorus - P	4.6	6.6	9.0	-	-	-	0.3	0.7	1.5	0.2	0.6	1.2
COD	55	130	300	-	-	-	26	36	54	15	20	24

PHASE II

Analysis of Effluents

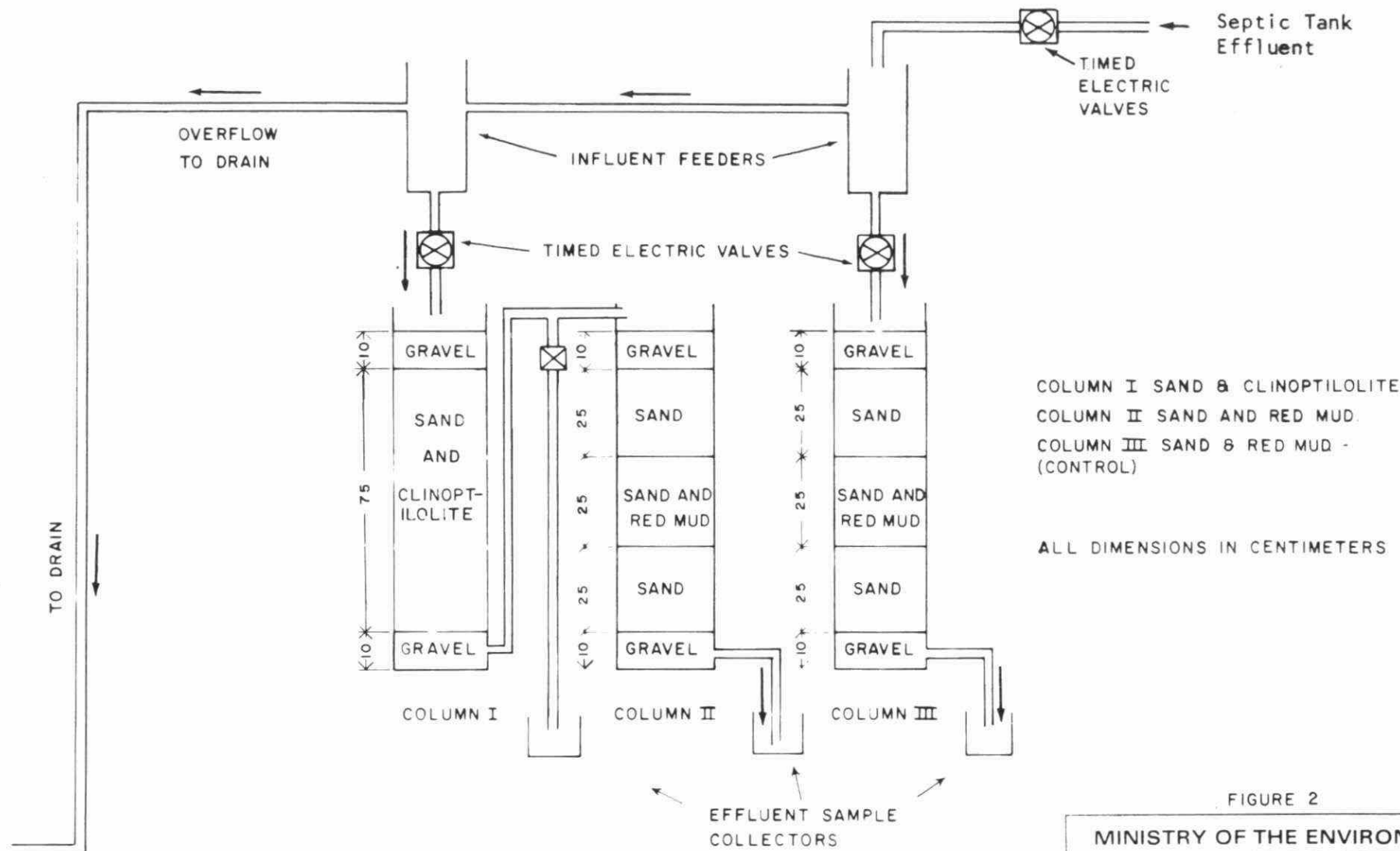
	Septic Tank Effluent			Effluent Column I Clinoptilolite			Effluent Column II Sand & Red Mud			Effluent Column III Sand & Red Mud					
	% O F T I M E V A L U E S E Q U A L T O O R L E S S T H A N														
	15	50	85		15	50	85		15	50	85		15	50	85
BOD	50	81	131		1.2	2.4	5.0		0.8	2.1	4.3		0.2	0.5	0.6
Suspended Solids	21	34	57		<5	10	15		<5	<5	<5		<5	<5	<5
Free Amonia (N)	18	23	28		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Total Kjeldahl - N	23	30	39		0.7	1.0	1.4		0.0	1.0	1.7		0.4	0.6	0.8
Nitrite - N	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Nitrate - N	<0.1	<0.1	<0.1		0.10	0.50	2.0		0.2	0.8	2.6		21.2	27.5	36.0
Phosphorus - P	5.0	6.5	8.8		1.0	1.9	3.7		0.08	0.2	0.5		0.4	0.5	0.6
C.O.D.	74	144	280		<20	20	30		20	30	50		<20	20	30



PHASE I

FIGURE I

MINISTRY OF THE ENVIRONMENT	
POLLUTION CONTROL BRANCH	
SCHEMATIC FLOW SHEET & ARRANGEMENT OF COLUMNS	
SCALE NONE	
DRAWN BY JBM	DATE SEPT 1978
CHECKED BY R.A.W	DRAWING NO. 8394



PHASE II

FIGURE 2

MINISTRY OF THE ENVIRONMENT
POLLUTION CONTROL BRANCH

SCHEMATIC FLOW SHEET &
ARRANGEMENT OF COLUMNS

SCALE NONE

DRAWN BY JBM

DATE SEPT 1978

CHECKED BY R.A.W.

DRAWING NO. 8394

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